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SEPARATED Σ^- BEAMS FOR BUBBLE CHAMBERS

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The intense fluxes of Σ^- hyperons predicted by Hagedorn-Ranft encourage one to think about the possibility of making bubble-chamber beams despite the severe decay losses. Such beams would probably open up a whole new region of the strange particle resonances since Y^* might be produced as copiously as N^*, and Ξ^* and as readily as Y^* are produced in pp interactions.

Since the length must be kept as short as possible, a modulated proton beam[1] is used. In order to achieve good momentum resolution without phase dispersion,[1] a double bend with intermediate focus is used. This also results in momentum recombination at the rf cavity. Quadrupole fields are modest and attainable with small bore conventional magnets. The deflection magnets required are 5 meters long with 40 kG and therefore must be superconducting. The target-to-cavity distance is 21.5 meters, and the wave length of the deflecting fields should therefore be between 0.8 and 1.0 cm, depending upon the relative importance of pion and antiproton background. The target-to-chamber fiducial volume distance is 39 meters so that 1 Σ in 1.5×10^5 survives to reach the fiducial volume of the chamber.

The beam length is essentially all magnet or slit so the length is approximately proportional to the momentum. Therefore approximately the same optics, decay losses, and fluxes are appropriate if all distances and magnet lengths are scaled with the momentum. Since the required deflector wave length is proportional to length divided by momentum squared, the deflector wave length must be scaled inversely as momentum when length is scaled with momentum. The larger cavities at lower momentum will not be filled by the simple scaling but a slight modification to fill the cavity will result in better separation. The longer wave length cavities are also closer to conventional X-band frequencies and are probably likely to benefit from rf-cavity superconducting technology sooner. Of course the analysis of the interactions of lower energy Σ^--p interactions is likely to be easier. It may also be richer since more general exchange reactions surely take place at modest momenta while Pomeron exchange may dominate at 80 GeV/c. The next step thus seems to me to be to check production of lower energy Σ^- by protons of less than the nominal 200 BeV and to design a lower energy beam if flux and background are no worse. The Σ^-, antiproton, and π^- fluxes will first be checked from Hagedorn-Ranft formula, but an experimental check of Σ^- flux even at AGS energies would clearly do a great deal to put such calculations on a firmer basis.

The details of the suggested beam will now be given. The design momentum is 80 GeV/c and the protons are assumed to target at 200 GeV although the first beam to be built should probably be lower momentum and should probably target at about 1.3 times the beam momentum in order to reduce background.

Targeting

The anticipated[2] extracted beam emittance of 0.4 mm-mrad (vertically) predicts an angular divergence of 0.1 mrad if the beam is 4 mm high. The conventional number of 6 MeV per meter[1,3,4] thus predicts a deflection of 0.36 mrad from 12 meters of rf deflector,[4] or a time varying deflection which is 3.6 times the instantaneous angular divergence. If the beam is now focused down to a (instantaneous) spot size of 0.1 mm, it will sweep across a centrally located target 0.1 mm high and will intercept it only with phase between $\sin^{-1}(-1/3.6)$ and $\sin^{-1} 1/3.6$ or -16 to $+16$ (plus, of course, $n \times 180$). If the target is one interaction length, the fraction of interacting protons is $1/2 \times 32/180 \approx 4\%$. An additional 4% have passed through the target but the remaining 92% could be restored to their original phase space by a similar set of deflectors placed after the target. The Hagedorn-Ranft curves[6] predict 20 Σ^- in the chamber for a beam of 5×10^{13} protons of which 20×10^{11} interact here. The target is assumed to be a ribbon, 0.1 mm thick, one interaction length wide in the beam direction and the effective width is set by the proton beam at 0.2 mm.

Optics

Figure 1 shows approximate calculation of maximum accepted angle rays from the center of the target in both planes. Effects due to finite image size are generally too small to be shown. Magnet sizes and strengths based on crude thin lens approximations are given in Table I. The first quadrupole forms a dispersed image through the first bending magnet. The magnification at the image is 2.6 so the image has a total width of 0.56 mm, the dispersion is 2 mm per percent, so a slit width of 1/2 mm would give a resolution of ±1/4%, although a broader transmission might be desirable. The third quadrupole forms a recombined image just after the rf cavity. The second lens forms a vertical image near the end of the third quadrupole. The magnification here is 0.7 so a slit 0.07 mm high would be desirable. Its function is primarily to degrade μ mesons from high momentum π's which decayed before the first bending magnet and which have the correct momentum but broaden the apparent target by the vertical projection of the decay angle. The number of such μ's is estimated in the section on background. The important point here is that μ's which scatter into the slit do not present a problem since they behave like beam π's and are deflected by the cavity to hit the stopper.

The fourth quadrupole forms an image on the beam stopper. The image size is 0.254 mm and the 4 meters of cavity produce a deflection of 1.8 mm. Figure 2 shows envelopes of deflected and undeflected images for a cavity wave length of 0.95 cm. Figure 3 is similar but for a cavity wave length of 0.777 cm, a better choice if there is a substantial antiproton background. The dotted lines show the effect of the finite bite in phase of the targeting. The last quadrupole forms a horizontal image through another 5 meter magnet at the start of the fiducial volume of the chamber.

Stopper Slit

Figure 4 shows a possible design of the slit. Muon escape by scattering would be prohibitive if a simple slit were used. A 1 mm septum can probably support a 15-kG field over this narrow gap if it is pulsed and perhaps cooled by nitrogen. One meter of such a field deflects a particle 5 mrad. The leakage back into a one meter long slit with tungsten walls would then be negligible.

Background

Since the chamber is 7° out of the beam line and 39 meters away, the direct background from target can probably be held at a tolerable level, and the important background is beam associated.

1. Beam-like pions. Taking into account the production ratio and Σ^- decay, 3×10^5 beam-like pions are accepted per Σ^- to reach the chamber. Most of these will hit the stopper. Elastic scattering back out of the slit looks negligible on the basis of a crude calculation. Lining the last magnet with a beam aperture slit will probably clean up the inelastic debris which escapes the slit. The slit should probably be 2 meters of tungsten.

2. <u>μ-mesons from the decay of beam-like pions.</u> The calculation of the beam-like μ intensity arising from the decay of these beam-like pions depends sensitively on how sharp momentum resolution can be achieved. A strict definition of $\Delta p = \pm 1/4\%$ predicts fewer than 10 such μ's per Σ in the chamber. A few hundred is perhaps more reasonable. Both 1 and 2 can be reduced by a factor of perhaps 5 by targeting at lower energy.

3. <u>Beam-like μ mesons from higher momentum pions.</u> An approximate treatment of the π production spectrum predicts about 1000 such beam-like μ mesons from π decay before momentum selection is achieved. Because of the vertical projection of the decay angles this will put a tail on the source image extending out to about 3 times its width. It is this tail which the vertical image definition slit after the third quadrupole is designed to mitigate. This background can surely be reduced by at least a factor of tem by targeting at a lower energy.

4. <u>Antiprotons.</u> The number of antiprotons is perhaps one percent of the number of pions. They are spread more by the finite phase spread of the targeting and are only about half as far from the Σ^- as are the π's at the stopper. The separation as shown is surely inadequate, but the intensity can be reduced substantially by targeting at a lower energy. Hence they probably do not pose a real problem.

The real insoluble problem is always μ mesons. The energy loss is about 2 BeV per meter of tung ten and the target-to-chamber distance is only 39 meters so they clearly cannot be stopped. Muons which hit slits early in the beam can be degraded enough to be driven out of the beam line, but magnetic shielding will surely be necessary to make them miss the chamber. Beam - like muons which hit the stopper can be degraded by a few BeV/c with high efficiency, but the scattering out of the degrader represents a few percent for energy losses of more than a few BeV. Even with more appropriate proton energy at targeting, the number of these beam-like μ mesons is not likely to be reduced below 50 per Σ^- in the chamber. Thus we are likely to have as many nearly beam-like π mesons as Σ in the chamber, and there will probably be at least ten times this many of substantially lower momenta which still hit the chamber. Of course, one always has π mesons of roughly 1/3 the Σ momentum from the Σ decay and neutrons of approximately the Σ momentum. The purity envisioned here probably precludes fluxes of more than two or three times Σ^- per pulse, but the background due to μ mesons is not significantly worse than that due to the inevitable decay products.

Alternative Approaches

Since about a third the length of the beam could be saved by making a single bend for momentum analysis, it is tempting to consider such a system. The condition for adequate isochronism as given by Berley[1] then limits the horizontal aperture in the magnet to about 1/5 deflector wave length and requires wave lengths about half those above. Such small aperture slits are not practical and the reduced acceptance more than offsets the gain from shorter length.

A longer system with a vertical focus at the first horizontal focus was investigated and the extra decay loss is too severe to justify any possible gain from the more elaborate optics.

Acknowledgments

It is a pleasure to thank Joe Lach and Dave Berley for suggesting the possibility of hyperon bubble-chamber beams to me. Don Meyer suggested the single momentum analysis beam and directed my attention to pulsed septum magnets to help the separation. George Trilling has emphasized the importance of targeting at a low energy and suggests moreover that perhaps separation is unnecessary if the target and beam energies are properly related.

Bill Fowler has revived my faith in the ability of cryogenic engineers to design support structure for superconducting coils, thus permitting me to place the last superconducting clearing magnet very close to the outer jacket of the proposed 25-foot chamber.

FOOTNOTES AND REFERENCES

[1]D. Berley, NAL Summer Study Report B. 3-68-41, 1968.

[2]Design Report National Accelerator Laboratory, July 1968.

[3]The Hagedorn-Ranft flux curves for 200-BeV protons are reproduced in Walker, NAL Summer Study Report B. 5-68-24.

[4]J. Lach, 200 BeV Accelerator: Studies on Experimental Use, Lawrence Radiation Laboratory UCRL-16830, Vol. I, 1964-65, p. 190.

[5]J. Lach, NAL Summer Study Report B. 3-68-43, 1968.

[6]Such a large deflection in a single long cavity would produce a displacement which would cause the beam to strike the irises. Breaking the cavity into two pieces and imaging the first into the second with a vertical transfer matrix of the form

$$\begin{pmatrix} -1 & 0 \\ 0 & -1 \end{pmatrix}$$

should help the situation. It is unlikely in any case that one could match the phase of the deflecting wave to the transmitted particle for 12 meters, so the cavity would have to be subdivided anyway.

Table I. Quadrupoles for Separated Hyperon Beams.

Quad	Length	Focal Length	Diameter	Gradient	Pole Tip Field
Q_1	2 m	1.8 m	2 cm	7.5 kG/cm	7.5 kG
Q_2	2	5	3	2.7	4.1
Q_3	2	2.8	3	4.8	7.2
Q_4	1	1.8	2	15	15
Q_5	1	3	4	9	18

All bending magnets are 40 kG, 5 m long magnets. D_1 requires a width of 50 cm in order to clear the proton beam. The beam is only 2 cm wide in D_2 and 0.5 cm in D_3.

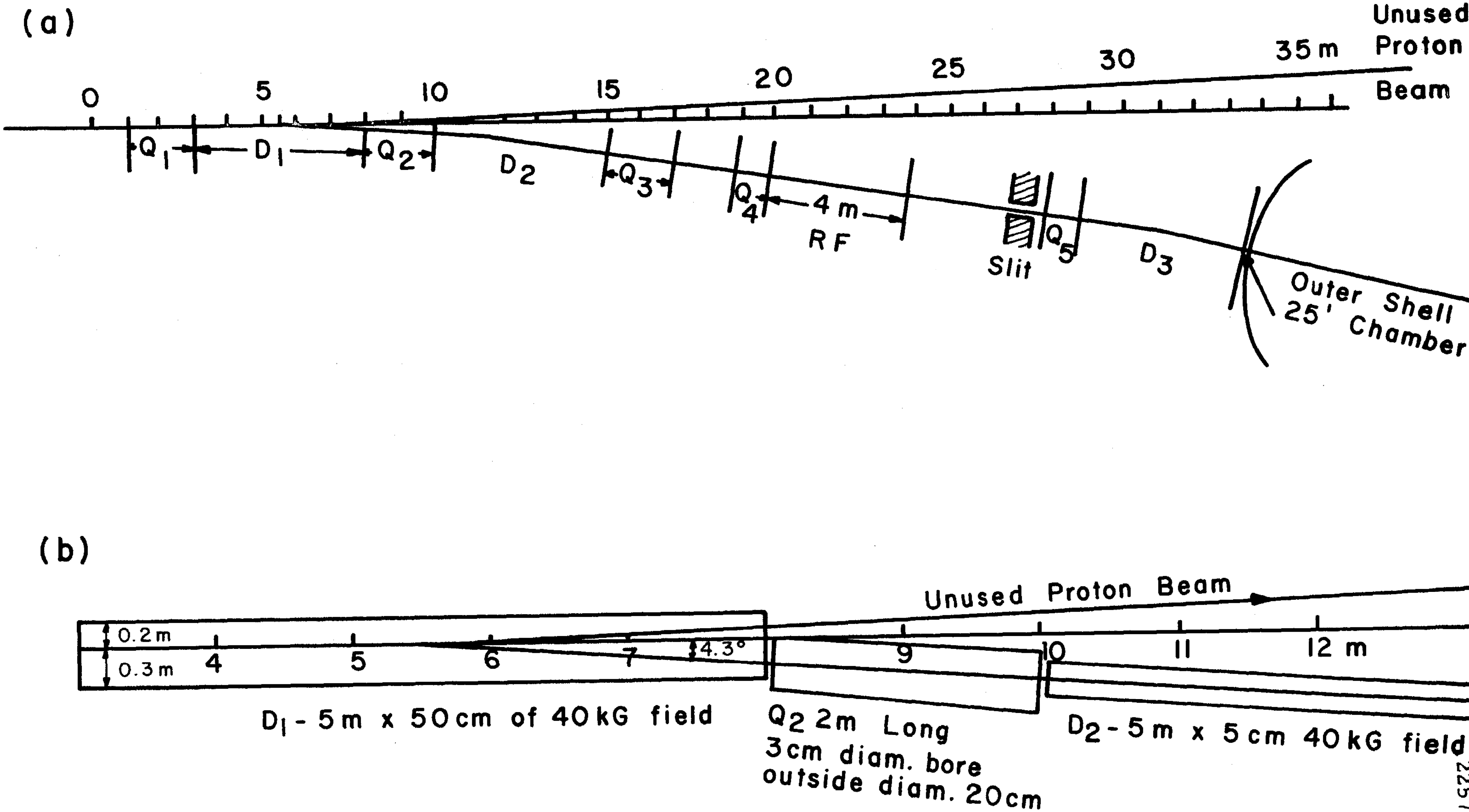

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Fig. 1A. (a) Plan view of separated hyperon beam. (b) Enlarged view of the first part of the beam.

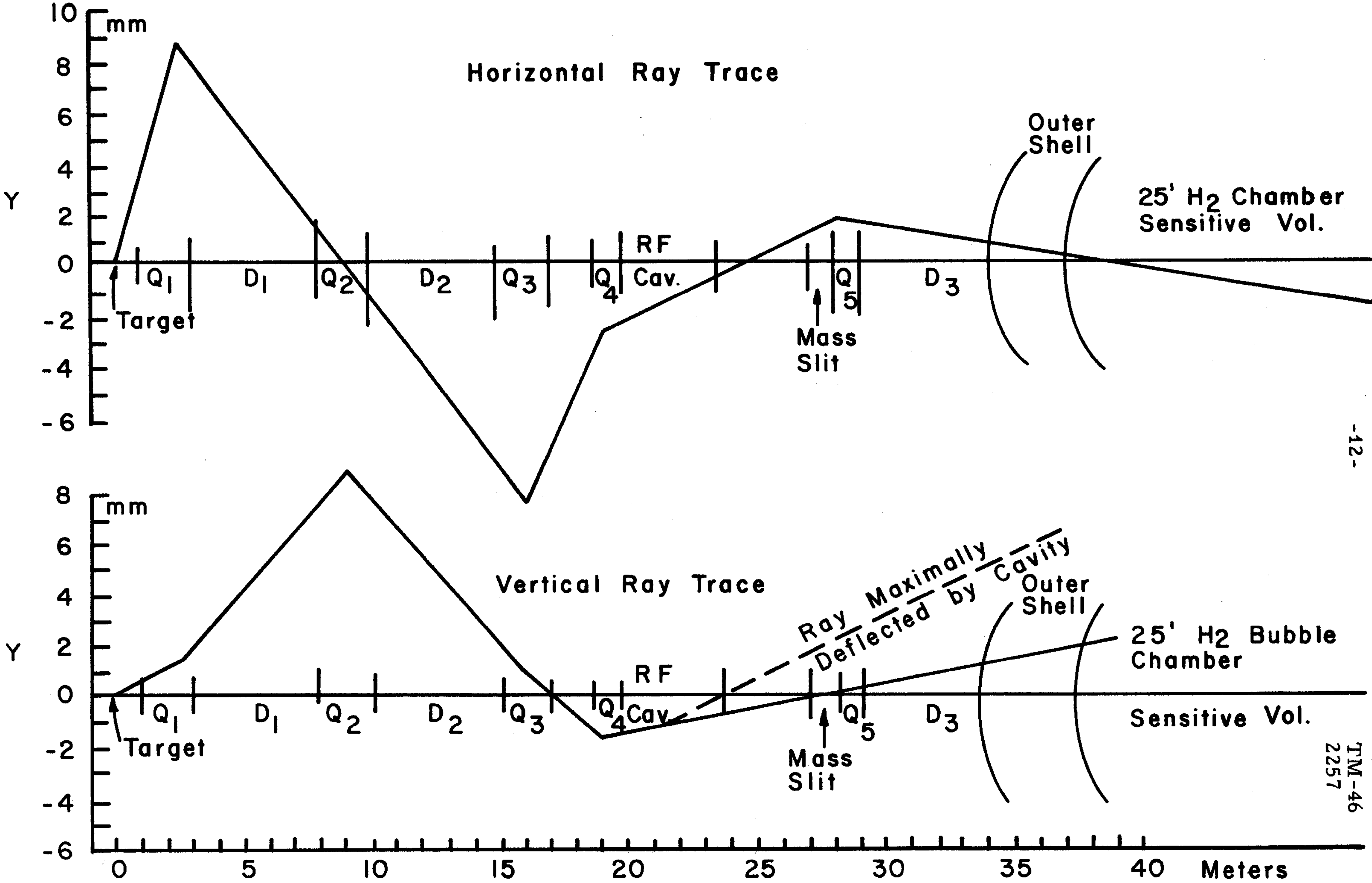

Fig. 1B. Horizontal and vertical ray traces of the separated beam.

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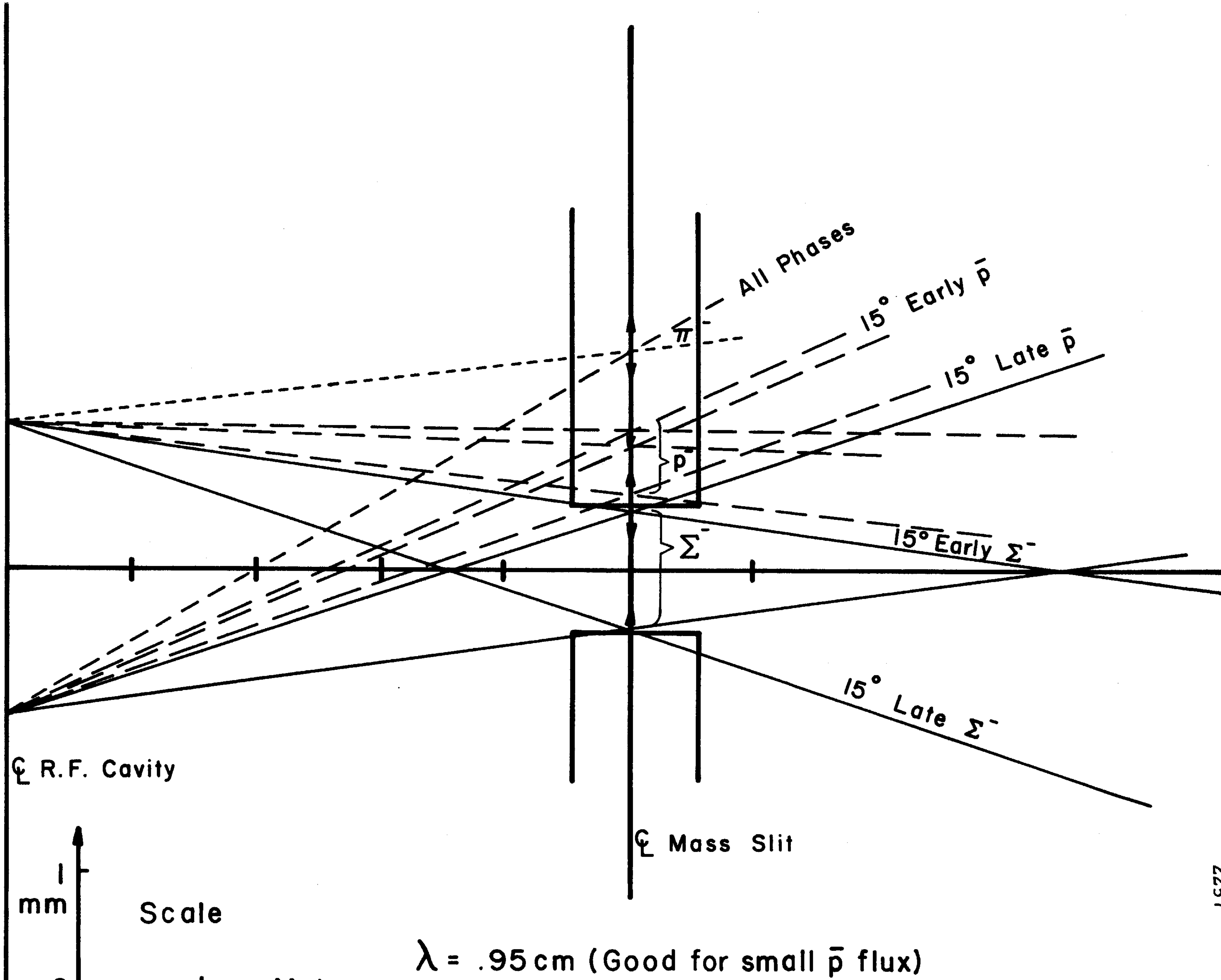

Fig. 2. Separation of different masses at the mass slit for

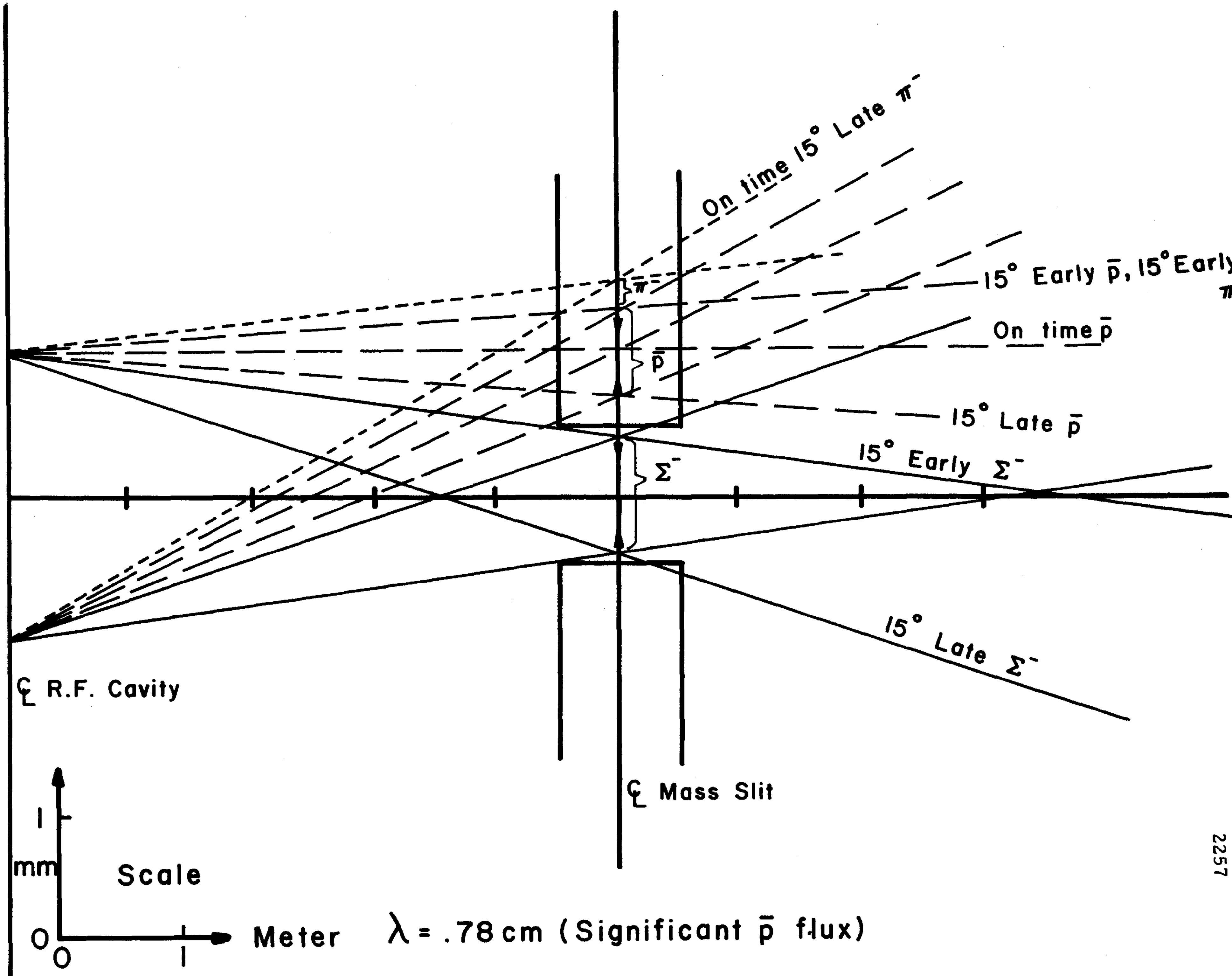

Fig. 3. Separation at the mass slit for λ = 0.78 cm.

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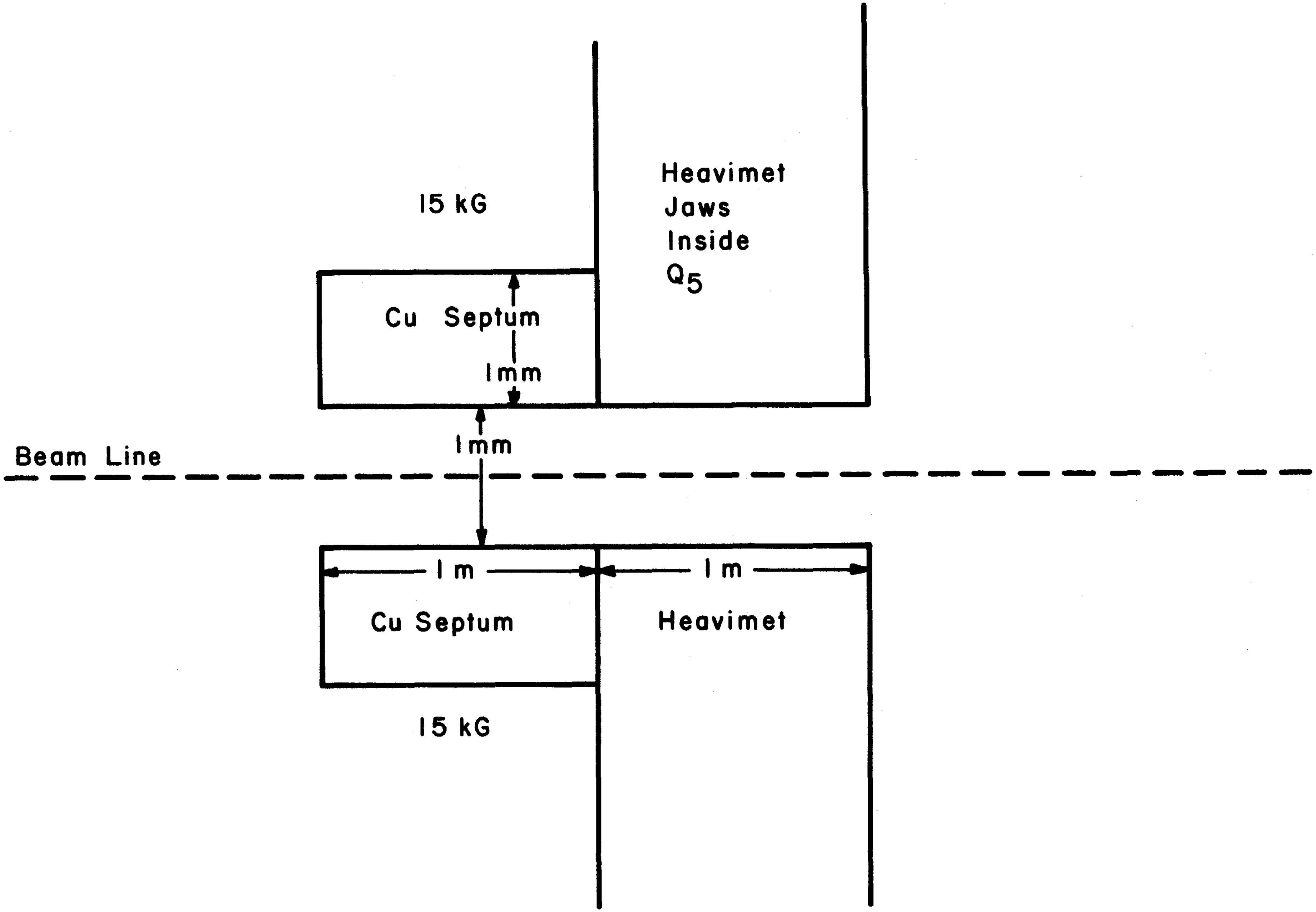

Fig. 4. Side view of the mass slit.